# Synthetic Aperture Sonar Low Frequency vs. High Frequency Automatic Contact Generation

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***Abstract*- Synthetic Aperture Sonar (SAS) bottom mapping sensors are on the verge of entering operational use. Here we examine the utility of both the low and high frequency output of SAS systems recorded from trials to determine their utility in the automatic contact generation scheme described in the companion paper "Automated Change Detection using Synthetic Aperture Sonar Imagery " [1]. The survey area covered by the trial has contacts called separately by the high and low frequency SAS output. The results are compared with a manual survey of the data to determine accuracy. The two frequency results are also compared by processing time. The data are then used to determine how merging the two outputs may yield an improved contact calling algorithm.**

## I. INTRODUCTION

Change detection is the process of comparing imagery collected in the past with imagery collected recently with an emphasis on noting which mine like objects are new and which are old between the two images. The imagery usually collected in a high value area, such as a port approach, that might be of concern to anyone attempting to detect mines at a later date. This process is currently performed manually in a labor intensive process. Our goal is to develop semi-automated and automated routines for detecting, labeling and reacquiring these objects. Up to now we have based our efforts on Side Scan Sonar imagery [,23,4]. In this paper and the companion paper [1] we wish to preliminarily examine how our detection tools translate into efforts based on Synthetic Aperture Sonar (SAS). Specifically, we wish to compare or combine the Low and High Frequency SAS available on Coastal Systems' Small Synthetic Aperture Minehunter (SSAM) Autonomous Underwater Vehicle (AUV) [5, 6].

The angular resolution of conventional radar is limited by the physical array length. Synthetic aperture processing virtually extends the array length by coherently adding array element responses over time as the array travels through the water. This effectively increases the array length – and therefore the angular resolution of the radar [7] – as long as the elements could be added with an accuracy of 90 degrees of phase or better (phase errors of less than 30 degrees are best). This concept was translated into the sonar world [8]; however, problems were noted due to the much lower speed of sound vs. the speed of light, which magnifies the effective relative motion of the sensor, target, and water column. This motion, and the difficulty of determining precise locations underwater, provided a challenge in producing the required phase error. In the 1990's, these problems were first overcome by mounting the system on a rail [9]. Since then, SAS has improved and is being used in UUV's [10], though the systems are still experimental. Here we explore the usefulness of both high and low frequency SAS in automatic object detection.

## II. SURVEY

In May 2009, researchers at the Naval Research Laboratory (NRL) participated in a homeland defense Limited Objective Experiment (LOE) with the Naval Oceanographic Office (NAVOCEANO) and the Naval Oceanography Mine Warfare Command (NOMWC) to look for mines in the Corpus Christi harbor [11]. At the start of the LOE, inert mineshapes were placed in the ship channel to simulate a terrorist threat. During the LOE, operators resurveyed the harbor with both sidescan sonar (on REMUS) and SAS (on the SSAM AUV) provided by NAVSEA Costal Systems Command. NOMWC, NAVOCEANO and NRL then analyzed the SSI and SAS to find the inert mineshapes.

## III. HIGH VS LOW FREQUENCY VISUAL COMPARISON

The SSAM AUV collecting this data set uses both a high and a low frequency SAS. In this section, we examine how our clutter finding algorithms initially performed on both high and low frequency data and compare these results with a visual scan of both high and low frequency data. The visual inspection was completed for the first day's run, which totaled about three hours, covered a 126 meter swath over almost three kilometers long, and produced 525 high frequency and 525 low frequency files.

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From the visual inspection, it was noted there was a large fish population in the survey area during the exercise, over a mostly sandy sea floor. Larger clutter items tended to be sadly the typical port area trash. Pipe sections and tires were the majority of these clutter items. Lesser noted items included 55 gallon barrels, cable, and wreck fragments.

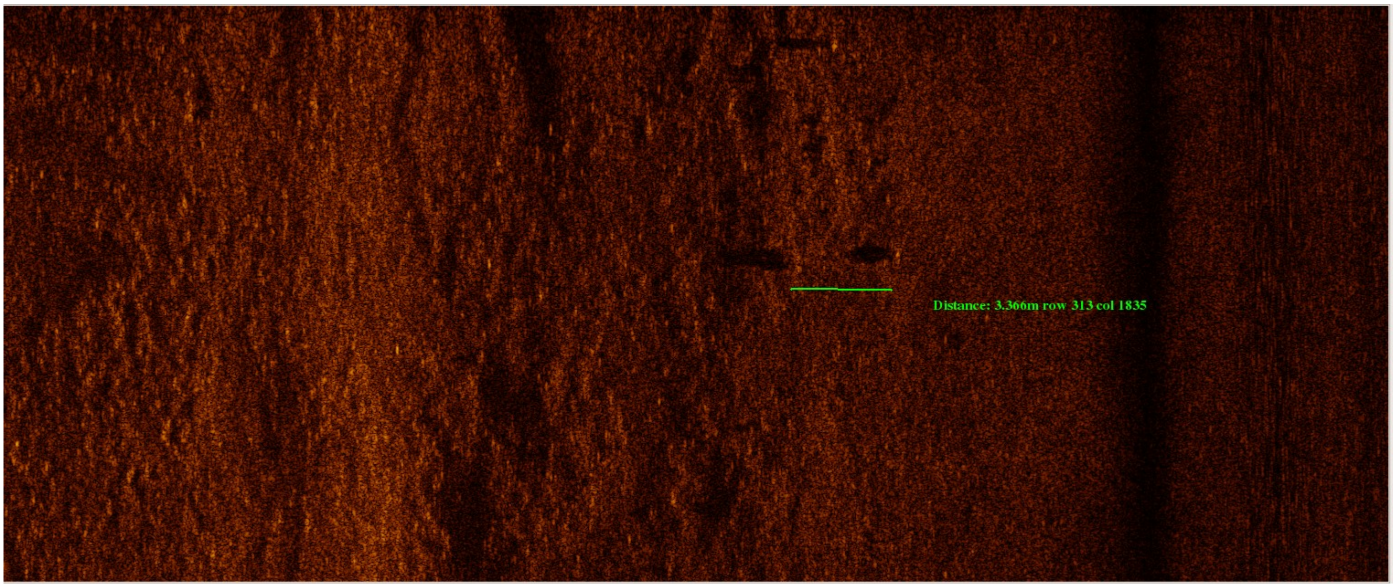


Figure 1. High frequency SAS view of the two contacts underlined with a green marker. Note there is another object directly above the contacts that we are discounting because of its small size.

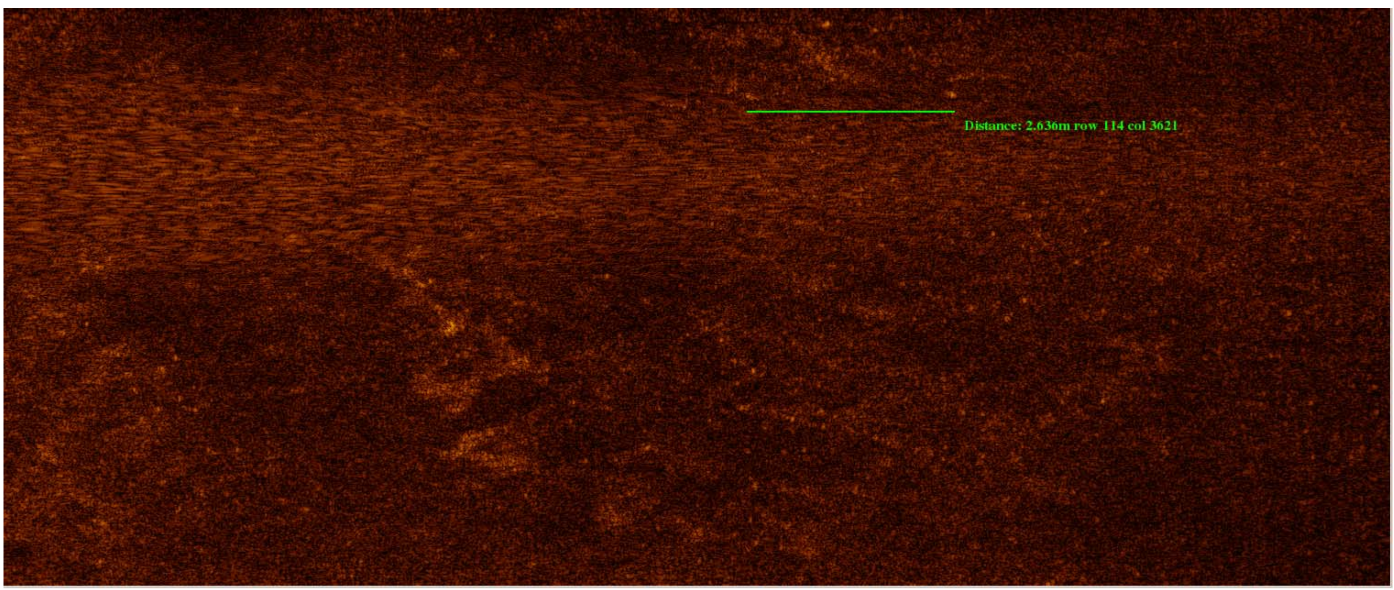


Figure 2. Same area viewed with low frequency SAS. Both views are pixel-by-pixel, so the lower view is stretched by a factor of two in the x direction and shrunk by a factor of three in the y direction.

Figures 1 and 2 illustrate both high and low frequency SAS views of the same area. For all data images, the image is oriented so that left-to-right movement is across the track of the data instrument, and top-to-bottom movement is along the track of the data instrument. The top of each image is later in time than the bottom. In the high frequency view, each pixel is 2.35cm square. Each processed high frequency image file is 2400 X 5184 pixels covering an area 56 meters along track and 122 meters across track. In the low frequency view, pixels are sharply rectangular with 1.17cm per pixel across track and 7cm per pixel along track. Each processed low frequency image file is 800 X 10368 pixels covering the same 56 X 122 meter area as the high frequency file.

This comparison between the high and low frequency images is typical for this data set. Each bottom object that would be labeled during change detection as an object of interest has a discernable shadow, though much fainter than the comparable side scan sonar image. Furthermore, objects can occasionally be imaged well enough to be initially classified. The low frequency views of these objects do not have discernable shadows unless the object is longer than 1.5 meters along track. Until objects are large enough to throw distinct shadows, they are not distinguishable from the background clutter. Figure 3 presents low and high frequency views of a 3 meter pipe object on the sea floor. Here the object is readily identifiable in the low frequency picture.

Researchers have been able to find buried objects using low frequency SAS under controlled conditions [12]. However, in the field, the combination of not knowing a priori where objects are, the low grazing angles involved, and the high prevalence of clutter on the order of the signal makes it highly unlikely that buried objects would be detected using this system and current signal processing (e.g., figure 2).

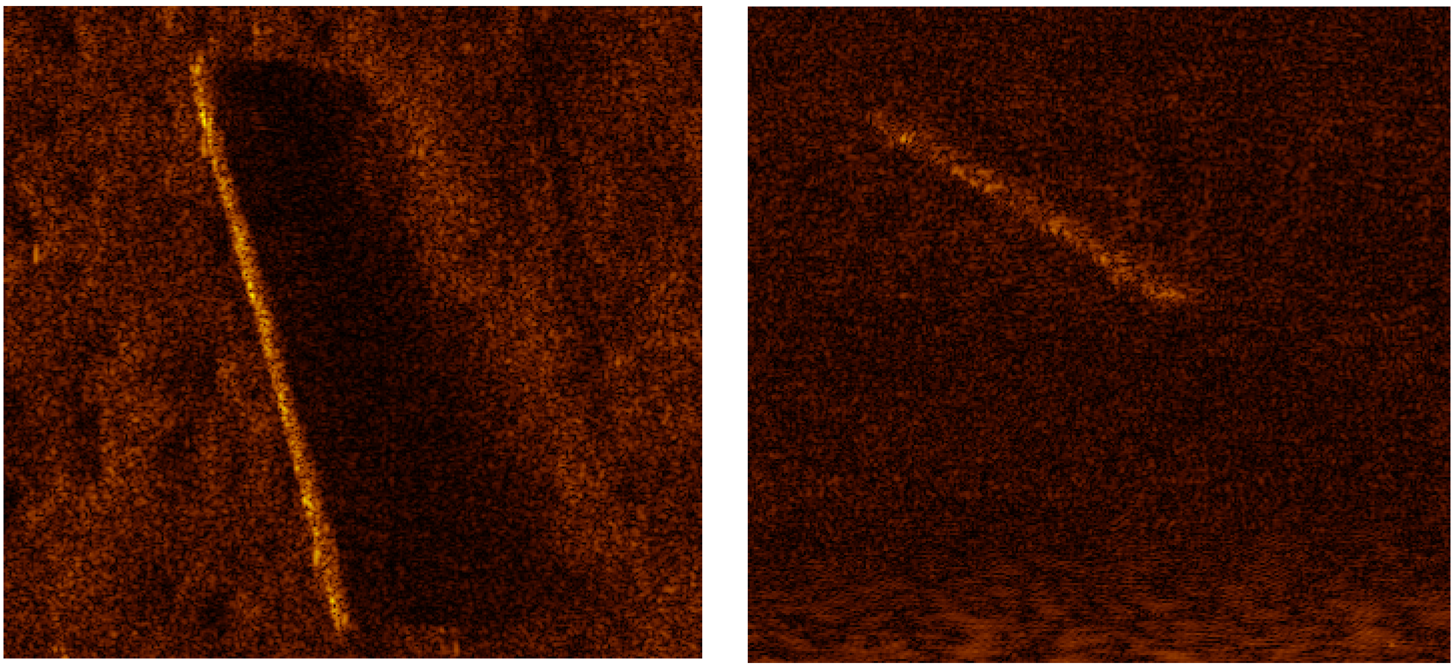

Figure 3. The image on the left is a high frequency close-up view of a 3 meter pipe. On the right is a low frequency close-up view of the same object, distorted as in Figure 2.

TABLE I
VISUAL VS CLUTTER FINDING COMPARISON

| | Visual | | Clutter Detect | |
|---|---|---|---|---|
| | Low Frequency | High Frequency | Low Frequency | High Frequency |
| Clutter Items Found | 18 | 172 | 0 | 16 |
| Clutter Items Missed | 154 | 0 | 172 | 156 |
| False Detections | 0 | 0 | 0 | 94 |

## IV. AUTOMATIC CLUTTER DETECTION

NRL’s Automated Target Recognition (ATR) algorithm [1] was applied to the high- and low-frequency imagery collected on the first day of the survey. Table I shows the visual vs automatic clutter detection. Due to the lack of shadow in the low-frequency data, it was expected that no targets would be detected by the ATR, which relies heavily on the presence of shadows associated with objects of interest. The high-frequency data contained shadows for many of the objects observed visually; however, these shadows were smaller and less well-defined than those typically found in conventional sidescan surveys. In addition, the bright

spots associated with objects were less intense and more distributed than found in sidescan surveys. While some targets were detected using our ATR algorithm tuned for conventional sidescan, it is clear the quality of the data needs to be improved and the ATR needs to be modified to effectively operate on SAS data.

## V. CONCLUSIONS

From the standpoint of change detection, the high frequency SAS clearly outperforms the low frequency SAS for proud objects under one meter in size; even for proud objects larger than one meter, high frequency SAS is still better. Low frequency SAS has a higher chance of finding buried objects [12] but given the current state of signal processing, it is unlikely to distinguish such objects. Future improvements of the SAS system may improve these findings. Even at the present state of the art, the survey data set is a valuable tool for exploring automatic detection algorithms given the variety of targets labeled during visual inspection of the data.

Given the large data sets created by SAS surveying, we would recommend only saving a downscaled 5 cm resolution, high frequency, mosaic image of the area. The mosaic image not only reduces the resolution but also reduces the overlap between images. We also recommend saving the snippet of the contact area in the high frequency look at full resolution. These recommendations would save the vast majority of pertinent information from the imagery with a factor of approximately 25 compression, compared to saving all survey data as received. This reduces the daily run storage to a point were it would fit on a 4 gigabyte DVD disk.

## ACKNOWLEDGMENT

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